APPENDIX A

APPENDIX A

Papers and Presentations with Analyses of NVNG MSS Sharing with Terrestrial Services, as Part of Preparations for WRC-97

	Title	Source	Forum	Date	Pages
1.	Co-frequency Sharing Between Non- GSO MSS below 1 GHz and LMS Systems, Comments and Discussion, Annex 3, Additional Analyses in Support of MSS and LMS Co-frequency Sharing	Leo One	Fax Distribution	7/17/97	2
2.	Non-GSO MSS Below 1 GHz, Earth-to-Space Transmissions, Background and Potential US Allocation Proposal	Leo One, FAI, E-Sat, ORBCOMM, STARSYS	Presentation to Wireless Bureau	3/13/97	12
3.	Additional Information on Frequency Sharing Between Non-GSO MSS (Narrowband Earth-to-Space Links) and LMS Systems	Leo One	IWG-2A of WAC-97, Doc. Addendum to Doc. IWG-2A/59 (Rev. 2)	2/13/97	4
4.	Cooperative Frequency Sharing Between the LMS and the NVNG MSS Uplinks in the Band 450-470 MHz	Leo One	Fax Distribution	2/5/97	4
5.	Preliminary Draft New Recommendation, Method for the Statistical Modelling of Frequency Sharing Between Stations in the Land Mobile Service Below 1 GHz and FDMA Non-Geostationary Satellite Orbit (Non-GSO) Mobile Earth Stations	WP8D	ITU-R Working Party 8D, Doc. 8D/TEMP/133, Attachment 1	11/5/96	14
6.	Frequency Sharing Between Non-GSO MSS (Narrow-Band Earth-to-Space Links) Below 1 GHz and LMS Systems	WP8D	ITU-R Working Party 8D, Doc. 8D/TEMP/135	11/5/96	5

7.	Spectrum Demand for Non-GSO MSS Below 1 GHz Services	WP8D	ITU-R Working Party 8D, Doc. 8D/TEMP/128	11/5/96	12
8.	Frequency Sharing Between Non-GSO MSS (Narrowband Earth-to-Space Links) and LMS Systems	USA	ITU-R Working Party 8D, Doc. 8D/150	10/21/96	37
9.	Frequency Sharing Between Non-GSO MSS (Narrowband Earth-to-Space Links) and LMS Systems	Leo One	WAC-97 IWG-2A, Doc. IWG-2A/59 (Rev. 2)	10/21/96	40

Leo One USA
July 17, 1997

Annex 3

Additional Analyses in Support of MSS and LMS Co-frequency Sharing

Sensitivity of MSS band-scanning receivers to short duration LMS transmissions
An input paper to the last WP 8D meeting (Doc. 8D/150) provided a detailed analysis of co-frequency sharing between non-GSO MSS networks and land mobile systems. Appendix A of Annex 3 of that document, "Band Scanning Receiver Sensitivity Analysis", provided information about the sensitivity of DCAAS type receivers to different duration signals. However, for brevity, that information was not preserved in the WP 8D output text from that meeting. The key results of that Appendix are reproduced below.

"The band-scanning receiver is significantly more sensitive to longer duration signals. Figure A-1 shows the in-band transmit power sensitivity for signal durations up to 0.5 seconds. The band-scanning receiver can detect a 0.5 second duration, 460 MHz, 2.5 kHz bandwidth, 3.5 mW transmit power signal anywhere in the satellite footprint with 99.9% probability. For a 16 kHz signal the sensitivity is 22 mW."

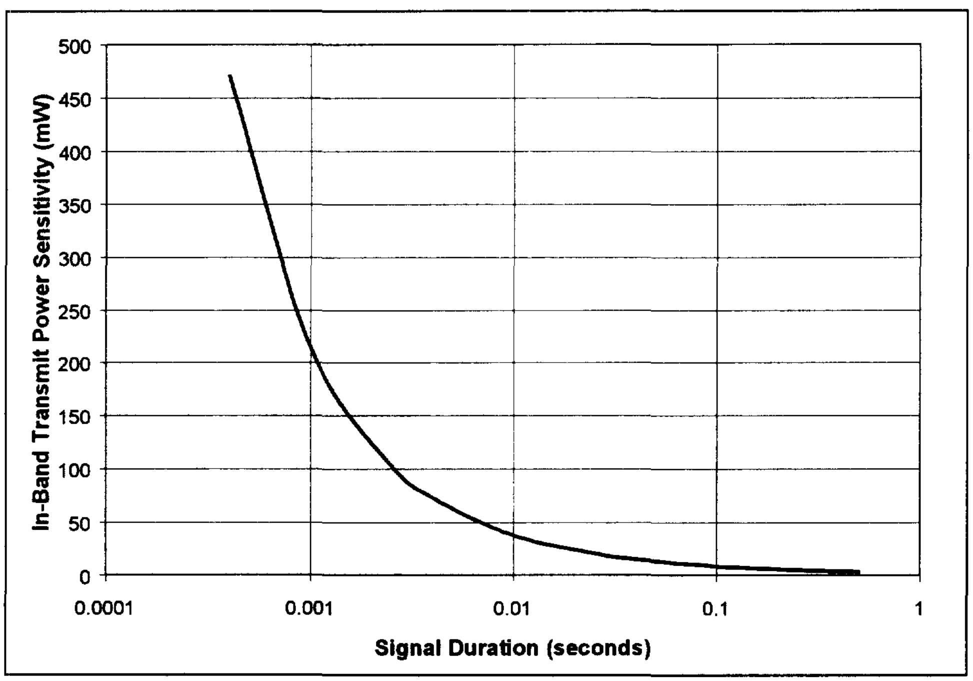

Figure A-1. Band Scanning Receiver Sensitivity as a Function of Signal Duration

By referring to Figure A-1, one may read the receiver sensitivity for signal durations shorter than 0.5 seconds. Specifically, for a 23 ms signal duration (a value cited by Israel at CPM-97 in document CPM97/80) the curve shows a sensitivity of about 30 mW for LMS transmitter power at 460 MHz. Generally, LMS transmitters greatly exceed this power level and would be very readily detectable by the MSS band scanning receiver.

Deviations from worst-case analyses used in the baseline scenario
The baseline scenario modeling incorporates several worst case-conditions which tend to produce very conservative results for the LMS environment specifically modeled. In other cases, more practical assumptions may be used to calculate average or typical results.

For modeling non-GSO MSS interference into LMS receivers, the worst-case conditions include:

1. Band scanning receiver fails to detect an active channel.
2. Full satellite beam is filled with land area containing active LMS systems.
3. Only one satellite is in view.

For modeling LMS transmitters interfering into satellite receivers of the MSS network, the worst-case conditions include:

1. Non-GSO MSS MESs transmitting at 100% of capacity 24 hours per day
2. Terrestrial LMS stations and non-GSO MSS MESs geographically clustered in the same areas
3. Satellite beam covering the whole of CONUS (most of the time the satellites will see large ocean areas and a lesser number of LMS stations in the beam because of rapid satellite motion and varying satellite ground tracks.)

When considering sharing cases other than those modeled, it may be appropriate to relax one or more of the worst-case conditions. Alternatively, additional worst-case conditions may need to be included for other cases.

Use of repeaters in land mobile networks
The basic criteria that determines the acceptability of the potential interference is the availability (as perceived by a user) for the particular channel that he is trying to use. When the user listens - if there is interference from a MES, the statistics as modeled in the baseline analysis fit the case. The fact that 5 or 10 or more other listeners are also experiencing interference from the same source does not change the availability of the signal to that particular user. When the user transmits - his channel availability for transmission is not changed by the fact that any interference that occurs may be "repeatered" to a number of receivers. The statistics are still valid for his channel. There is certainly a greater effect (in number of listeners affected) when a repeatered channel suffers interference, however the statistics on availability for any one user are unaffected by the number of other participants in the communication.

LMS channels with varying traffic loading rates
The baseline analysis results are directly scaleable to account for different traffic loading levels. Of course, if there are channels that are continuously in use, the band scanning receivers in the MSS satellites would preclude those channels from being used for MES transmissions.

Non- GSO MSS Below 1 GHz, Earth-to-Space Transmissions, Background and Potential US Allocation Proposal

EFM -3/13/97

1. Introduction

The non-geostationary orbit mobile satellite service (non-GSO/MSS) below 1 GHz is a developing low bit rate service that can provide useful communications services to the United States and to the world. Among the communications services offered are automated meter reading, remote asset tracking, vehicle messaging, personal messaging, and supervisory control and data acquisition (SCADA).

Market demand analysis has shown that the projected need for spectrum for non-GSO/MSS system uplinks by 2002 is 13.6 MHz on a shared basis. This is greater than the current allocations, so there is a need for additional uplink spectrum accessibility. (Draft CPM Report, section 4.1.1.14, identifies the need for additional spectrum for non-GSO/MSS.)

There are no frequency bands below 1 GHz available to be used for non-GSO/MSS uplinks on an exclusive basis. Therefore, sharing with existing services is required.

An examination of the spectrum availability and use below 1 GHz has found that a candidate band for shared use is the band 450 - 470 MHz, currently allocated to and used by the land mobile service. It is proposed that this band be shared by the LMS and the non-GSO/MSS uplinks on a co-primary basis.

An allocation of a bandwidth greater than the minimum required bandwidth would provide a flexibility of use by the non-GSO/MSS that would allow sharing with the LMS on a worldwide basis despite differences in assignments and use of these frequencies terrestrially from region to region and by different administrations.

2. Co-frequency sharing between the LMS and non-GSO MSS uplinks

Potential interference from a non-GSO MSS uplink to a land mobile receiver is a localized event. For interference to occur:

1. The mobile earth station (MES) must be close enough to a LMS receiver to exceed a threshold of received interfering power.
2. The LMS receiver and the MES transmitter must be on the same channel.
3. The LMS receiver must be receiving a wanted signal at the instant that the MES is transmitting.

Non-GSO MSS narrowband systems have characteristics that are amenable to frequency sharing with the LMS.

- Transmissions are digital data transmitted via packets using short bursts (less than 500 ms)..
- Individual MES transmissions are limited to low duty cycle, and aggregate use of a channel for non-GSO MSS uplinks can be limited to typically 1% or less.
- Non-GSO MSS systems have frequency agility - the ability to use any available channel for uplinks.
- Assignments of uplink channels to be used are made on an instantaneous basis under control of the satellites in the system, using a technique of dynamic channel assignment. Each satellite has a band-scanning receiver that continuously monitors the operating uplink band for channels that are temporarily unused by the LMS.
- This dynamic channel assignment technique avoids the use of LMS channels that are currently in use.

Potential additional interference to LMS systems is very small

- System integrity even for critical services is maintained.
- Potential decrease in channel availability is no more than 0.1%.
- This small change in availability can readily be accommodated by existing methods of providing redundancy and insuring successful transmissions.

3. Sharing analyses of potential interference to LMS receivers

With the use of dynamic channel assignment techniques by the MSS network, and the inherent frequency agility of the mobile earth stations (MESs), channels currently in use by the LMS are avoided by the satellite network.

There are some situations where the band-scanning receivers in the satellites will not detect an active LMS channel, for example:

- LMS power level below the detection threshold of the satellite band-scanning receiver,
- Blockage on the path from the LMS transmitter to the satellite so the received signal is not high enough to be detected,
- A LMS transmitter begins operation on a channel during a MSS transmission on what had been previously measured as a clear channel.

3.1 Models used in sharing analyses at 148 - 149.9 and 460 MHz

Analyses were performed for the <u>infrequent</u> cases where the band-scanning receiver does not detect an active LMS channel. In all other cases, there is no interference.

Commonly occurring scenario used - Mobile transceivers in the LMS and relatively low height MESs in the non-GSO MSS network

- LMS equipment characteristics - Mobile transceivers, either analog or digital, with 6 dBi gain antennas, and 10 meters antenna height product.
- Non-GSO MSS network characteristics - 950 km altitude circular orbits, narrowband FDMA Earth-to-space links, store-and-forward operation, short duration (less than 500 ms) and low duty cycle (typically 1%) packet communications, MESs with 0 dBi gain antennas at 3m height.

3.2 Results of analyses

Channel availability requirements for LMS systems

- Typical service availability provided by LMS systems has been 90%, and the design availability for critical services such as police and fire safety has been indicated as 99%.
- Interference from a satellite system has been typically allowed to increase unavailability by an additional 10%. This same criteria would result in 1.1% unavailability for the critical services and 11% unavailability for the other services, or availibilities of 98.9% and 89%, respectively.
- This degradation of availability is considered acceptable by those land mobile users that will allow this negligibly small amount of additional unavailability. (Several land mobile service user associations maintain that no amount of additional interference is acceptable.)

Numerical results of simulations

- For the cases studied (different channel bandwidths, satellite data rates, and LMS receiver distributions), the potential interference was found to degrade the availability of the channel for LMS use by much less than 0.1% or equivalently much less than one 100 ms interference every 100 seconds.
- The analysis that determined these probabilities to be so low, was a multiple worst case analysis for mobile transceivers in the LMS. The more general case, without simultaneous worst case conditions, would have even lower probabilities of interference.

Other considerations:

Potential for squelch activation -

The probabilities calculated in the analyses are the probabilities for C/(N+I) dropping below a threshold value. Merely crossing this threshold does not activate the squelch circuit. Much greater interference power is required to activate squelch, and this occurs with much lower probability.

Effect on a previously clear channel -

If a LMS transmitter begins operation on what had previously been a clear channel, the interference probability would be as modeled but multiplied by p_c (the probability of a free channel being used by a MES and then also being selected for use by an LMS system). p_c is less than one, and may be in the range 0.1 to 0.25.

Doppler shift -

Doppler shift of signals is taken into account by the dynamic channel assignment system. When a clear channel is identified by the satellite receiver, the permission to transmit Earth-to-space is for the MES to transmit at a frequency such that the signal when it arrives at the satellite (after Doppler shift) occupies the identified clear channel. Any LMS systems operating near the MES would experience the same degree of Doppler shift, and would have been detected by the band-scanning receiver. Therefore, because of the localized interference (MSS to LMS), the Doppler shifts are accommodated by the dynamic channel assignment system, even though the channels may be shifted in frequency as seen by the band-scanning receiver.

Application to other cases:

Broader bandwidth shared by the LMS and the non-GSO MSS -

The analyses performed modeled a shared bandwidth of 1 MHz. If a broader bandwidth were shared by the two services, say 20 MHz (450-470 MHz), the interference potential would be reduced at least in a linear manner, in this case by at least 20 to one. Or alternately, a greater number of non-GSO MSS systems could be accommodated with the same interference probability. In general, a broader shared bandwidth reduces the potential for interference. So to provide greater protection against interference for the LMS, one should allocate a greater shared bandwidth.

LMS base stations with increased antenna heights -

With higher antennas there are correspondingly larger areas of potential interference. The LMS community indicated that the area of potential interference would expand by a factor of 30. However, the probabilities of interference modeled are so low that even with 30 times the interference area, the criteria of no more than 10% increase in unavailability could be met for a 99% availability channel.

Increased height of MES transmitter -

Some MES transmitters may be on fixed buildings and may have a greater antenna height than modeled. This would occur in a minority of cases. The area of potential interference would increase, but the calculated probabilities would still allow the availability criteria to be met. Additionally, there would be site shielding provided by the building in some of the locations, which would diminish the interference potential.

Use of repeaters in the LMS -

The basic criteria that determines the acceptability of the potential interference is the availability (as perceived by a user) for the particular channel that he is trying to use. When the user listens - if there is interference from a MES, the statistics as modeled fit the case. The fact that 5 or 10 or more other listeners are also experiencing interference from the same source does not change the availability of the signal to that particular user. When the user transmits - his channel availability for transmission is not changed by the fact that any interference that occurs may be "repeatered" to a number of receivers. The statistics are still valid for his channel.

High density of MESs in urban markets -

It is pointed out that the non-GSO MSS systems will not have the capacity to serve their total potential markets in urban areas, and that this may result in a greater concentration of MESs in urban areas than had been modeled and this in turn would lead to greater interference to the LMS systems. This argument leads one to conclude that the systems can not be used in a manner that would lead to greater interference. In this situation, there would also be increased difficulty in finding available uplinks. So the case is somewhat self-limiting. Small capacity systems cannot effectively provide total communications needs in urban areas.

4. Potential interference from LMS transmitters into non-GSO MSS satellite receivers and the availability of uplink channels

With dynamic channel assignment techniques used by the satellites, Earth-to-space transmissions will be received at the satellites only on channels not being used at that time by LMS transmitters. The potential problem is the availability of a sufficient number of clear uplink channels to provide the needed transmissions within the NVNG MSS.

4.1 Models used, 148-149 MHz and 460 MHz

LMS and non-GSO MSS system characteristics as described earlier

Multiple worst case conditions used in the simulation, including:

1) non-GSO MSS MESs transmitting at 100% of capacity 24 hours per day
2) terrestrial LMS stations and non-GSO MSS MESs geographically clustered in the same areas
3) satellite beam covering the whole of CONUS (most of the time the satellites will see large ocean areas and a lesser number of LMS stations in the beam because of rapid satellite motion and varying satellite ground tracks.)

Four different land mobile station activity factors, three land mobile channelization plans, and three MES uplink data rates were modeled.

4.2 Results of simulation to determine availability of uplink channels

- With 25 kHz land mobile system channelization, 2.4 kbps MES uplink data rate, and .006 Erlang activity factor, 285,000 terrestrial mobile stations could operate within the satellite footprint (12 million km^2) and still leave a minimum of 6 clear channels for MES uplink transmission in 5 MHz of shared bandwidth.
- In 20 MHz of shared bandwidth, there could be about 1.5 million terrestrial stations and 6 clear channels still available for MSS use.
- Since on the average, only 30% of CONUS is in view of a particular satellite, there could be more than 5 million terrestrial stations in CONUS and an average of six clear uplink channels would still be available.
- These simulation results for potential LMS interference into MSS satellite receivers were also input to international Working Party 8D of the ITU-R. The Working Party 8D conclusion was that with frequency sharing, as studied, a sufficient number of clear channels (6) could be found for MSS uplinks.

4.3 Application to other cases

Density of transmitters in the LMS networks

- Information has been supplied on the density of LMS transmitters in the US: 12 million in the bands near 150 MHz, 450 MHz, and 470-512 MHz, with about 4 million in the 450-470 MHz band[2]. The results previously cited for 20 MHz bandwidth that more than one million additional LMS transmitters could be accommodated in the 450-470 MHz band and there would still be available at least six channels for MSS uplinks.

- Greater availability of uplink channels would occur in practice because of several additional factors:
    1. non-uniform distribution of LMS transmitters across the 20 MHz
    2. multiple satellites in view much of the time
    3. satellites beams viewing mostly ocean much of the time
    4. acceptable delays in non-GSO MSS transmissions to avoid the LMS busy hours.
- (Within about six minutes, a satellite viewing full CONUS moves to viewing about 50% ocean.) With these factors as variances from the worst case simulations used, it is concluded that there would be a sufficient number of clear channels to provide for the non-GSO MSS uplink transmissions in a shared bandwidth of 20 MHz.

Effects of re-farming

With re-farming of the LMS bands there will be a reduction in channel bandwidths to 12.5 kHz and 6.25 kHz. Using the simulations already performed and the factor of 30% of CONUS in view, the number of mobile station transmitters in CONUS that would allow six clear channels to be found are about 10 million and 25 million, for 12.5 kHz and 6.25 kHz channel bandwidths, respectively, in the band 450-470 MHz.

5. Conclusions

Analyses and simulations have shown that frequency sharing between non-GSO MSS uplinks and LMS stations is feasible in the frequency bands 450-470 MHz under a regimen where the burden of sharing (additional equipment, operational complexity, and new technology) is born entirely by the MSS systems.

The LMS systems may continue to operate as if the MSS systems were not in the band at all. The very small decrease in availability (less than 0.1%) would be handled by the existing techniques and procedures currently used by the LMS systems to combat other outages due to, for example, blockage, multipath, rain attenuation, or LMS self-interference.

The more difficult sharing situation is the availability of uplink channels for the MSS. Shared allocation of the wide bandwidth (20 MHz) makes this problem solvable.

In the US, with 25 kHz channelization, there are 800 LMS channel slots in the band 450-470 MHz. If each channel is geographically reused only 20 times within CONUS (as assumed in the simulation[1]), 16,000 LMS channels are available in CONUS. For non-GSO MSS uplinks with the equivalent of six full-time, clear channels, only 6/16000 or 0.04% of the available LMS channel capacity would be used by the non-GSO MSS. And those six equivalent channels would be obtained by short duration, low duty cycle usage in the intervals between LMS messages. The proposed shared allocation is not an unreasonable request.

6. Draft proposal for co-frequency sharing by the LMS and the non-GSO MSS in the band 450-470 MHz

Use of a 450 -470 MHz non-GSO MSS allocation is a three step process:

1. an international allocation would be made at WRC-97 for the entire band thereby providing the framework for flexible use of the frequencies by the non-GSO MSS,
2. individual administrations would make their domestic allocations for the band or parts of the band,
3. the granting of licenses to the non-GSO MSS systems by individual administrations according to their plan for domestic use, taking into account the national uses of the band, which may further constrain the local use of the international allocation.

As can be seen, details of specific use of the band may vary from region to region and from country to country. However the initial broad international allocation would provide the flexibility for the development of global non-GSO MSS networks to provide needed communications services throughout the world.

Specific proposal

Article S5

MOD

MHz
450 – 470

Allocation to Services		
Region 1	Region 2	Region 3
450 – 455	FIXED MOBILE MOBILE-SATELITE (Earth-to-space) MOD S5.209 S5.271 S5.286 MOD S5.286A	
455 – 456 FIXED MOBILE MOBILE-SATELLITE (Earth-to-space) MOD S5.209 MOD S5.286 A S5.286B S5.271	**455 – 456** FIXED MOBILE MOBILE-SATELLITE (Earth-to-space) MOD S5.209 S5.271 MOD S5.286A S5.286B S5.286C	**455 – 456** FIXED MOBILE MOBILE-SATELLITE (Earth-to-space) MOD S5.209 MOD S5.286A S5.286B S5.271

<table>
<tr><td colspan="3">456 – 459
FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space)
S5.271 S5.287 S5.288
MOD S5.209 MOD S5.286A</td></tr>
<tr><td>459 – 460
FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space)
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S5.271</td><td>459 – 460
FIXED
MOBILE
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S5.286B
S5.286C</td><td>459 – 460
FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space)
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S5.286B
S5.271</td></tr>
<tr><td colspan="3">460 – 470
FIXED
MOBILE
MOBILE-SATELLITE (Earth-to-space)
Meteorological-Satellite (space-to-Earth)
S5.287 S5.288 S5.289 S5.290
MOD S5.209 MOD S5.286A</td></tr>
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Reasons:

To expand allocation to world-wide to make use of global coverage features of non-GSO MSS systems. Studies have shown feasibility of sharing with fixed and mobile systems. Allocation in bands as shown allows selection of different mobile satellite service channels in different parts of the world to accommodate varying intensities of use by the mobile service and by other services.

MOD S5.209 The use of the bands 137 - 138 MHz, 148 - 149.9 MHz, 400.15 - 401 MHz, and 450 ~~- 455 - 456 MHz and 459 -~~ 470 MHz by the mobile-satellite service and the bands 149.9 - 150.05 MHz and 399.9 - 400.05 MHz by the land mobile-satellite service is limited to non-geostationary satellite systems.

Reasons:

To extend the limitation to non-geostationary satellite systems to the band 450 - 470 MHz.

MOD S5.286A The use of the band~~s 455 - 456 MHz and 459 - 460~~ 450 - 470 MHz by the mobile-satellite service is subject to coordination under Resolution **46 (Rev. WRC-95)**/No. **S9.11A**.

Reasons:

To extend the coordination procedures to the band 450 - 470 MHz for the non-geostationary MSS systems.

Addendum to Doc. IWG-2A/59 (Rev. 2)
February 13, 1997

Submitted by: LEO ONE
Final Analysis
Orbcomm
STARSYS
E-Sat
CTA

Additional Information on Frequency Sharing Between Non-GSO MSS (Narrowband Earth-to-Space Links) and LMS Systems.

1. Introduction

Doc. IWG-2A/59 (Rev. 2) presents results of studies that show the feasibility of non-geostationary orbit mobile satellite service (non-GSO MSS) systems (narrowband earth-to-space links) sharing the same frequency band with mobile transceivers in land mobile service (LMS) systems, for a particular scenario and for specific characteristics of the LMS system and the non-GSO MSS network. Discussions with the LMS community have revealed that the equipment characteristics and use of the LMS bands vary widely, and consequently, no single analysis scenario can fully represent the wide range of sharing situations encountered. This addendum extends the application of the sharing analysis to other scenarios and also clarifies several technical points raised by the LMCC (Land Mobile Communications Council) in document IWG-2A/57 and in discussions within IWG-2A.

2. Characteristics of the LMS system and of the non-GSO MSS network used in the analysis

LMS system characteristics used are given in detail in Doc. IWG-2A/59 (Rev. 2) in section 2.2 and also in section 2.3 of Annex 2. Important characteristics for this addendum are: mobile LMS transceivers, either analog or digital, with 6 dBi gain antennas, and 10 meters antenna height product.

Non-GSO MSS network characteristics are those of the Leo One network and are given in Doc. IWG-2A/59 (Rev. 2) in section 2.1 and also in section 2.1 of Annex 2. Important non-GSO MSS characteristics for use in this addendum are 950 km altitude circular orbits, narrowband FDMA Earth-to-space links, store-and-forward operation, short duration (less than 500 ms) and low duty cycle (typically 1%) packet communications, mobile earth stations (MESs) with 0 dBi gain antennas at 3m height.

3. Clarification of the analyses and simulations performed

3.1 Commonly occurring scenario used

The analyses and simulations in Doc. IWG-2A/59 (Rev. 2) are for the commonly occurring scenario of mobile transceivers in the LMS and relatively low height MESs in the non-GSO MSS network, with the characteristics as given in the previous section.

The analysis has provided one scenario of what has been described by the LMS community as a very diverse collection of systems, operators and equipment. No single scenario could characterize all of the possible interference situations. One could always find scenarios where the sharing is easier, and also scenarios where the sharing is more difficult. The scenario examined in Doc. IWG-2A/59 (Rev. 2) is for an appropriate baseline analysis from which to expand to other scenarios.

3.2 Probability of interference when dynamic channel assignment technique fails to detect an active LMS channel

The results of the analysis are used only to calculate the probability of interference with dynamic channel assignment in use, but where the system fails to detect an active LMS channel. For the case of a low power LMS system where the transmitter power is not high enough to be detected by the band-scanning receiver, the interference probabilities would be as calculated in Annex 2 of document IWG-2A/59 (Rev. 2). For the case of signal blockage causing the dynamic channel assignment technique to not identify an active channel, the interference probability would be as calculated in Annex 2 but multiplied by p_b (the probability of signal blockage.) p_b is certainly less than one, and may typically be in the range 0.1-1.0%. For the case of a LMS transmitter beginning operation in what had previously been a clear channel, the interference probability would be as calculated in Annex 2 but multiplied by p_c (the probability of a free channel being used by a MES and then also being selected for use by an LMS system). p_c is less than one, and may be in the range 0.1 to 0.25. Thus, in the identified cases where the dynamic channel assignment technique fails to fully prohibit the possibility of interference, the probability of interference from MES transmitters to LMS mobile receivers may be acceptably low, for LMS systems that can accept 0.1% additional degradation of availability.

3.3 Dynamic channel assignment systems at 450 MHz

A dynamic channel assignment technique (DCAAS) was already successfully demonstrated at 149 MHz using an operational NVNG MSS satellite. The technology can be applied as well in the bands 450 - 470 MHz without any technical difficulties. The front end amplifiers and mixers that would be needed to operate at 450 MHz are essentially the same designs (but scaled upward in frequency) as those used at 149 MHz. Additionally, digital signal processing will allow "instantaneous" determination of channel usage by the LMS, so there is no time penalty associated with scanning a broader bandwidth.

3.4 Interference thresholds used

In the analyses and simulations, interference was assumed to exist if the calculated ratio C/(N+I) fell below 10.7 dB. In an analog FM system, this would produce an occasional click. In a digital system, a bit error rate of 10^{-3} would be produced for non-coherently demodulated binary-FSK without forward error correction. In an FM system, the interference at this threshold level would not activate the receiver squelch circuit. In a digital system, error correction would improve the bit error rate at threshold. In both FM and digital systems, the signal does not fall apart when the interference threshold is met.

3.5 Interference effects on LMS channel availability

It is recognized that there is a need to keep very small any additional interference to land mobile systems, especially those that are critical, such as police, fire, and transportation. These systems are already designed to provide redundancy or to repeat transmissions to cover transmission outages. Any additional interference that may be provided by the satellite system would need to be at a level, duration, or repetition rate such that the land mobile system integrity would be maintained. The sharing regimen used in the analyses of Doc. IWG-2A/59 (Rev. 2) takes advantage of all three, using only temporarily unused channels, short duration transmissions, and low duty cycles.

The dynamic channel assignment system in the MSS network identifies which channels are instantaneously unused by the LMS and assigns only unused channels for MES uplink transmissions, thereby avoiding interference into LMS receivers. There is the small possibility that the dynamic channel assignment system will fail to detect an active channel (due to blockage, low power, or some other reason). For those small number of cases, a statistical simulation technique was used to determine the probability of interference to a LMS receiver and the mean time between interference events. For the cases studied (different channel bandwidths, satellite data rates, and LMS receiver distributions), the potential interference was found to degrade the availability of the channel for LMS use by much less than 0.1% or equivalently much less than one 100 ms interference every 100 seconds. (Typically, interference from a satellite system has been allowed to increase unavailability by an additional 10%.) Typical service availabilities provided by LMS systems have been 90%, and the design availability for safety services has been indicated as 99%. The 0.1% decrease in availability would amount to a 10% increase in unavailability for a 99% available channel, and a 1% increase in unavailability for a 90% available channel. This degradation of availability is considered acceptable by those land mobile users that will allow this negligibly small decrease in availability. (Several land mobile service user associations maintain that no amount of additional interference is acceptable.)

The analysis that determined these probabilities to be so low, was a multiple worst case analysis for mobile transceivers in the LMS. The more general case, without simultaneous worst case conditions, would have even lower probabilities of interference. These analyses were submitted internationally to the meeting of Working Party 8D of the ITU-R in early November. Among the conclusions reached at that meeting was that frequency sharing, as modeled, would produce infrequent interference to the land mobile service.

In the US, with 25 kHz channelization, there are 800 LMS channel slots in the band 450-470 MHz. If each channel is geographically reused only 20 times within CONUS (as assumed in the simulation in Doc. IWG-2A/59 (Rev. 2)), 16,000 LMS channels are available in CONUS. For NVNG MSS uplinks with the equivalent of six full-time, clear channels, only 6/16000 or 0.04% of the available LMS channel capacity would be used by the NVNG MSS. And those six equivalent channels would be obtained by short duration, low duty cycle usage in the intervals between LMS messages, with no burden of new technology, complex operational procedures, or additional equipment for the LMS systems. The 0.04% figure listed above is an upper bound on the interference that could be caused by one non-GSO MSS network as modeled and operating in a shared bandwidth of 20 MHz. It may be interpreted as the maximum amount of interference that would be generated if every transmission resulted in interference. Of course, with the use of active channel avoidance, as planned, the interference percentage and the consequent decrease in channel availability for the LMS would be very much lower, as shown by the analyses and simulations.

3.6 Limitations on duty cycle

There is a misunderstanding of how the MSS Earth-to-space links would cause potential interference to LMS receivers. The requirement is that the MSS uplink cause interference no more frequently than x% of the time to any particular receiver. This does not translate to an x% duty cycle on the MSS system. Let's say that a particular transmission causes interference to a receiver located in Washington, DC. If fifteen seconds later, that same uplink channel is used by a MES in San Francisco, even if it causes interference there, it has not affected the availability of the channel in Washington, DC. Because of the wide geographical distribution of the MSS earth stations, and the fairly localized effects of their potential interference, the duty cycle for use of a channel by a MSS system could be many, many times greater than x%.

3.7 Effects of squelch activation in the LMS receivers

The probabilities calculated in Doc. IWG-2A/59 (Rev. 2) are the probabilities for C/(N+I) dropping below a threshold value. Merely crossing this threshold does not activate the squelch circuit. Much greater interference power is required to activate squelch, and this occurs with much lower probability. Additional analysis would be required to quantify this effect.

3.8 Effect of delay on use of a previously clear channel

There is a misunderstanding of the operation of the dynamic channel assignment technique. Reference is made to one second after a clear channel is identified, a land mobile transmission could come onto that channel, thereby blocking the satellite mobile earth station. Within one second, the MES has finished its transmission. The dynamic channel assignment system would then prohibit transmissions on the channel after the LMS system has come on. The band scanning receiver would examine channel use at a rate of twice per second or greater. The described potential problem would not occur.

3.8 Doppler shift

The concern about Doppler smearing indicates a misunderstanding of how the MSS systems would operate. When a clear channel is identified by the satellite receiver, the permission to transmit earth-to-space is for the MES to transmit at a frequency such that the signal when it arrives at the satellite (after Doppler shift) occupies the identified clear channel. Any LMS systems operating near the MES would experience the same degree of Doppler shift, and would have been detected by the band-scanning receiver. Therefore, because of the localized interference (MSS to LMS), the Doppler shifts are accommodated by the dynamic channel assignment system.

4. Application of the analyses and simulations to other scenarios

The analysis for calculating interference into LMS receivers in Doc. IWG-2A/59 (Rev.2) assumed multiple worst case conditions: 1) non-GSO MSS mobile earth stations (MESs) transmitting at 100% of capacity, 24 hours per day, 2) terrestrial stations and non-GSO MSS MESs geographically clustered in the same areas, and 3) dynamic channel avoidance not effective. Similarly, for the determination of the availability of a sufficient number of clear channels for uplinks to the MSS satellites, multiple worst case conditions were used in the simulation, including: 1) non-GSO MSS MESs transmitting at 100% of capacity 24 hours per day, 2) terrestrial LMS stations and non-GSO MSS MESs geographically clustered in the same areas, 3) satellite beam covering the whole of CONUS (most of the time the satellites will see large ocean areas and a lesser number of LMS stations in the beam because of rapid satellite motion and varying satellite ground tracks.) Because of the worst case conditions used in both of the interference situations, the results may be quantitatively applied to other scenarios with confidence that the availability criteria may still be met.

4.1 Increased height of base station antennas

For the case of LMS base stations, which were not modeled, there are higher antennas and correspondingly larger areas of potential interference. Document IWG-2A/57 indicates that the area of potential interference would expand by a factor of 30. However, the probabilities of interference modeled are so low that even with 30 times the interference area, the criteria of no more than 10% increase in unavailability could be met for a 99% availability channel.

4.2 Increased height of MES transmitter

Some MES transmitters may be on fixed buildings and may have a greater antenna height than modeled. These may occur in a minority of cases, and the probabilities would still allow the availability criteria to be met. Additionally, there would be site shielding provided by the building in some of the locations, which would diminish the interference potential.

4.3 Use of repeaters in the LMS

The basic criteria that determines the acceptability of the potential interference is the availability (as perceived by a user) for the particular channel that he is trying to use. When the user listens - if there is interference from a MES, the statistics as modeled in Do. IWG-2A/59 (Rev. 2) fit the case. The fact that 5 or 10 or more other listeners are also experiencing interference from the same source does not change the availability of the signal to that particular user. When the user transmits - his channel availability for transmission is not changed by the fact that any interference that occurs may be "repeatered" to a number of receivers. The statistics are still valid for his channel.

4.4 High density of MESs in urban markets

It is pointed out that the non-GSO MSS systems will not have the capacity to serve their total potential markets in urban areas, and that this may result in a greater concentration of MESs in urban areas than had been modeled and this in turn would lead to greater interference to the LMS systems. This argument leads one to conclude that the systems can not be used in a manner that would lead to greater interference. In this situation, there would also be increased difficulty in finding available uplinks. So the case is somewhat self-limiting. Small capacity systems cannot effectively provide total communications needs in urban areas.

4.5 Density of terminals in the LMS network

The results of the simulations in Doc.IWG-2A/59 (Rev. 2) indicate that with 25 kHz land mobile system channelization, 2.4 kbps MES uplink data rate, and .006 Erlang activity factor, 285,000 terrestrial mobile stations could operate within the satellite footprint (12 million km^2) and still leave a minimum of 6 clear channels for MES uplink transmission in 5 MHz of shared bandwidth. In 20 MHz of shared bandwidth, there could be about 1.5 million terrestrial stations and 6 clear channels still available for MSS use. Since on the average, only 30% of CONUS is in view of a particular satellite, there could be more than 5 million terrestrial stations in CONUS and an average of six clear uplink channels would still be available.

Information has been supplied on the density of LMS transmitters in the US: 12 million in the re-farming bands near 150 MHz, 450 MHz, and 470-512 MHz, with about 4 million in the 450-470 MHz band. The results cited in the previous paragraph indicate that up to about one million additional LMS transmitters could be accommodated in the 450-470 MHz band and still provide six available channels for MSS uplinks. Greater availability of uplink channels would occur in practice because of several additional factors: 1) non-uniform distribution of LMS transmitters across the 20 MHz, 2) multiple satellites in view much of the time, 3) satellites beams viewing mostly ocean much of the time, 4) acceptable delays in NVNG MSS transmissions to avoid the LMS busy hours. (Within about six minutes, a satellite viewing full CONUS moves to viewing about 50% ocean.) With these factors as variances from the worst case simulations used, it is concluded that there would be a sufficient number of clear channels to provide for the NVNG MSS uplink transmissions in a shared bandwidth of 20 MHz. The simulation results in Ref. 1 for potential LMS interference into MSS satellite receivers were also input to international Working Party 8D of the ITU-R. The Working Party 8D conclusion was that with frequency sharing, as studied, a sufficient number of clear channels (6) could be found for MSS uplinks.

4.6 Effects of re-farming

Consider the effect of re-farming the LMS bands and the subsequent reduction in land mobile channel bandwidths to 12.5 kHz and 6.25 kHz. Using the simulations referred to in the preceding section and the factor of 30% of CONUS in view, the number of mobile station transmitters in CONUS that would allow six clear channels to be found are about 10 million and 25 million, for 12.5 kHz and 6.25 kHz channel bandwidths, respectively, in the band 450-470 MHz.

E.F. Miller
February 5, 1997

Cooperative Frequency Sharing Between the Land Mobile Service (LMS) and the Non-Voice Non-Geostationary Mobile Satellite Service (NVNG MSS) Uplinks in the Band 450 - 470 MHz

NVNG MSS is a developing low bit rate service that can provide useful communications services to the United States and to the world. Among the services that would be offered are automated meter reading, remote asset tracking, vehicle messaging, personal messaging, and supervisory control and data acquisition (SCADA). Market demand analysis has shown that the projected need for spectrum for NVNG MSS system uplinks by 2002 is 13.6 MHz on a shared basis. This is greater than the current allocations, so there is a need for additional uplink spectrum accessibility.

The spectrum below 1 GHz is intensely used by a number of services. There are no open frequency bands to be used for NVNG MSS uplinks on an exclusive basis. An examination of the spectrum availability and use below 1 GHz has found that a candidate band for shared use is the band 450 - 470 MHz, currently allocated to and used by the land mobile service. It is proposed that this band be shared by the LMS and the NVNG MSS uplinks on a co-primary basis, with the burdens of new technology, operational procedures, and additional equipment to facilitate sharing being born entirely by the satellite service. It is proposed that the LMS be a passive partner in the sharing arrangement, with no additional technological burden and no additional costs. A shared bandwidth of 20 MHz is considered, because a greater shared bandwidth makes the frequency sharing easier, as will be discussed later.

To achieve this co-primary frequency sharing, Mobile Earth Stations (MESs) in the NVNG MSS will be authorized to transmit only on channels that are temporarily not being used by the LMS anywhere within the coverage beam of the satellite. Satellites will use dynamic channel assignment receivers to continuously monitor the channel activity. (A dynamic channel assignment technique {DCAAS} was already successfully demonstrated at 149 MHz using an operational NVNG MSS satellite. The technology can be applied as well in the bands 450 - 470 MHz, and additionally, digital signal processing will allow "instantaneous" determination of channel usage by the LMS.) Information on available channels will be transmitted to all MESs within the satellite beam. Doppler shift of the LMS transmitters and the MESs is taken into account to insure that MES transmissions are not on the same frequencies as those being used locally by the LMS, and also to insure that signals received at the satellite occur only on clear channels. MES transmissions will be short duration (500 ms or less) and low duty cycle (1% maximum).

Because the NVNG MSS use of these bands is predicated upon operation on a non-interference basis with the LMS, and because the burden of sharing this frequency band would be born entirely by the satellite system, the formal proposal for modification to the Radio Regulations might appropriately include a footnote similar to S5.286B which was developed at WRC-95 for the Region 2 NVNG MSS allocations (Earth-to-space).

[S5.286B Stations in the mobile-satellite service in the bands 455-456 MHz and 459-460 MHz shall not cause harmful interference to, or claim protection from, stations of the fixed or mobile services.]

With co-frequency sharing proposed there are two possibilities for mutual interference: 1) MES transmitters interfering into LMS receivers, and 2) LMS transmitters interfering into NVNG MSS satellite receivers. The following sections analyze and evaluate these possibilities and show that the two services can share the frequency band.

Potential Interference to LMS Receivers: It is recognized that there is a need to keep very small any additional interference to land mobile systems, especially those that are critical, such as police, fire, and transportation. These systems are already designed to provide redundancy or to repeat transmissions to cover transmission outages. Any additional interference that may be provided by the satellite system would need to be at a level, duration, or repetition rate such that the land mobile system integrity would be maintained. The sharing regimen proposed takes advantage of all three, using only temporarily unused channels, short duration transmissions, and low duty cycles.

The dynamic channel assignment system in the MSS network identifies which channels are instantaneously unused by the LMS and assigns only unused channels for MES uplink transmissions, thereby avoiding interference into LMS receivers. There is the small possibility that the dynamic channel assignment system will fail to detect an active channel (due to blockage, low power, or some other reason). For those small number of cases, a statistical simulation technique was used to determine the probability of interference to a LMS receiver and the mean time between interference events[1]. For the cases studied (different channel bandwidths, satellite data rates, and LMS receiver distributions), the potential interference was found to degrade the availability of the channel for LMS use by much less than 0.1% or equivalently much less than one 100 ms interference every 100 seconds. (Typically, interference from a satellite system has been allowed to increase unavailability by an additional 10%.) Typical service availabilities provided by LMS systems have been 90%, and the design availability for safety services has been indicated as 99%. The 0.1% decrease in availability would amount to a 10% increase in unavailability for a 99% available channel, and a 1% increase in unavailability for a 90% available channel. This degradation of availability is considered acceptable by those land mobile users that will allow this negligibly small decrease in availability.

The analysis that determined these probabilities to be so low, was a multiple worst case analysis for mobile transceivers in the LMS. The more general case, without simultaneous worst case conditions, would have even lower probabilities of interference. These analyses were submitted internationally to the meeting of Working Party 8D of the ITU-R in early November. Among the conclusions reached at that meeting was that frequency sharing, as modeled, would produce infrequent interference to the land mobile service.

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